Cognitive Neuroscience of Figurative Language

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1 Introduction

On pornography, U.S. Supreme Court Justice Potter Stewart famously wrote, “I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description; and perhaps I could never succeed in intelligently doing so. But I know it when I see it…” (cited in Gewirtz, 1993). The same might be said for figurative language. Usually defined in opposition to literal language, figurative language encompasses a variety of rhetorical techniques, such as metaphor, personification, hyperbole, and many others, all used to increase the affective and inferential impact of one’s statements. Though most scholars have rejected a dichotomous division between literal and figurative language (Coulson and Lewandowska-Tomaszczyk, 2005), it remains a useful heuristic for talking about particular figures of speech.

Figurative language is an important topic in psycholinguistics for a number of reasons. First, while many people think of figurative language as confined to artistic venues, it is in fact far more common than many people realize (Gibbs, Wilson, and Bryant, this volume). Second, the diversity of figurative language highlights the range of different cognitive processes people bring to bear on language production and comprehension. Finally, the study of figurative language has led to an important locus of generativity in language, namely the human ability to map within and between concepts, frames, and scenarios (Coulson, 2001).

Despite the importance of figurative language, to date it has attracted relatively little attention from cognitive neuroscientists. This is changing, however, both because of advances in our understanding of the neural underpinnings of basic word and sentence processing, and because researchers in the field have begun to understand the importance of figurative language in everyday communication (see, e.g., the special issue of Brain & Language devoted to the neural correlates of nonliteral language [Giora, 2007]). One area of particular interest stems from the observation of brain-injured patients, namely the role of the nondominant right hemisphere (RH) in the production and comprehension of figurative language.
Whereas left hemisphere (LH) lesions are frequently associated with deficits in core language ability, such as the production of fluent, grammatical speech, or the comprehension of spoken words and sentences, the incidence of such aphasic deficits is far less common in patients with lesions in the RH (Heeren and Consoli, 1973). Instead, patients with RH damage present with more subtle deficits involving the relationship between an utterance and its context. Besides socially inappropriate remarks and digressions of topic, such deficits have been argued to include various kinds of figurative language (Joanette, Goulet, and Hannequin, 1997). For example, RH damaged patients have been shown to have difficulty understanding jokes (Bihlle, Brownell, and Gardner, 1986; Brownell et al., 1987), interpreting sarcastic utterances (Giora, 2003; Rehak, Kaplan, and Gardner, 1992), and have been characterized as deriving overly literal interpretations of metaphoric language (Winner and Gardner, 1977).

One consequence of these observations of the disparate effects of LH and RH damage is that traditional (propositional) distinctions between literal and nonliteral meaning have been invoked to explain them. Thus, the left hemisphere is often associated with language processing commonly construed as literal, while the right hemisphere has been associated with nonliteral processing, including figurative language as well as other sorts of pragmatic phenomena that depend upon extra-linguistic knowledge for their interpretation. In a selective review of research on the cognitive neuroscience of figurative language, we address the veracity of classic assumptions about lateralization and the distinction between literal and nonliteral language. Moreover, we address how the methods of cognitive neuroscience have been used to test models of figurative language comprehension.

The chapter focuses on two well-studied examples of figurative language: jokes and metaphors. We begin each section with a review of cognitive neuroscience research used to test and develop models of the comprehension of these phenomena, and follow with a review of evidence for the importance of the RH in each. We conclude with some speculations about how the potential relevance of recent advances in other areas of cognitive neuroscience impacts the study of figurative language, and general issues relevant to meaning in language.

2 Joke comprehension

Though language researchers have traditionally looked to syntax as the chief source of our productive language capacity, another important source of productivity in language arises from the interdependence of the meaning of a word and the contextual assumptions that surround its use. For example, it is impossible to understand the meaning of weekend without an understanding of the structure of the week, as well as the cultural knowledge that many people in industrialized countries work Monday through Friday, and not on Saturday and Sunday (Fillmore, 1976). This context dependence in meaning has been explored in frame semantics, a research program in cognitive linguistics in which a word’s semantic properties are described with respect to how they highlight aspects of an associated frame or a structured set of background assumptions. Langacker argues that while rose and caviar refer to the same thing, their meanings differ because rose presumes a biological frame while caviar presumes a culinary one (Langacker, 1987). Conversely, Lakoff argues that the different meanings of mother, as in my birth mother versus my adopted mother, rely on different frames for parenthood (Lakoff, 1987).

The study of joke comprehension addresses the importance of frames for language comprehension, since many jokes are funny because they deceive the listener into using the wrong frame to help interpret the information presented in the first part of the joke. For example, consider the following joke: “I let my accountant do my taxes because it saves time; last spring it saved me ten years.” Initially, the listener activates a busy-professional frame. However, at the punch line “saved me ten years,” it becomes apparent that a crooked-businessman frame is more appropriate. Although lexical reinterpretation plays an important part in joke comprehension, to truly appreciate this joke it is necessary to recruit background knowledge about particular sorts of relationships that can obtain between business people and their accountants so that the initial busy professional interpretation can be mapped into the crooked businessman frame. The semantic and pragmatic reanalysis to understand jokes like this is known as frame shifting (Coulson, 2001).

3.1 Cognitive electrophysiology of joke comprehension

The neurophysiology of language processes can be investigated in healthy people via the noninvasive recording of event-related brain potentials (ERPs). ERPs are small voltage fluctuations in the electroencephalogram (EEG) that are time-locked to perceptual, motor, or cognitive events collected by recording EEG while participants perform a recording task such as reading (Rugg and Coles, 1995). By averaging the EEG time-locked to multiple tokens of a given type (e.g., the onset of a word used metaphorically), it is possible to isolate aspects of the electrical signal that are temporally associated with the processing of that type of event (such as understanding a metaphoric meaning). The result of averaging is a waveform with a series of positive and negative peaks, known as components, and labeled by reference to their polarity (‘P’ for positive-going and ‘N’ for negative-going), and when they occur relative to the onset of the stimulus event, or relative to other ERP components.

Over the last twenty-five years, cognitive neuroscientists have identified ERP components associated with processing different sorts of linguistic information, such as the link between the N400 and semantic integration processes. The N400 component of the ERPs was first noted in experiments contrasting sentences that ended sensibly and predictably with others that ended with an incongruous word. Congruous words elicited a late positive wave, while incongruous endings elicited a negative wave beginning about 200 ms after word onset and peaking at 400 ms (Kutas and Hillyard, 1980). Subsequent experiments have shown that finer gradations of semantic context also modulate N400 amplitude. For example, amplitude shows a strong inverse correlation with the predictability of the eliciting word within a given sentence context (Kutas, Lindamood, and Hillyard, 1984). In general, experimental manipulations that make semantic integration more difficult result in larger amplitude N400, while those that facilitate it result in smaller N400 (see Van Berkum, this volume).

Given the impact of frame shifting on the interpretation of one-line jokes, one might expect the underlying processes to be reflected in the brain’s real-time response. Coulson and Kutas compared ERPs elicited by sentences that ended as jokes that required frame shifting with nonsense “straight” endings consistent with the contextually evoked frame (Coulson and Kutas, 2003). Two types of jokes were tested, high constraint jokes such as (1) which elicited at least one response on a sentence completion task with a close probability of greater than forty percent, and low constraint jokes like (2) which elicited responses with close probability abilities lower than forty percent. For both (1) and (2) the word in parentheses was the most popular response on the cloze task.

(1) I asked the woman at the party if she remembered me from last year and she said she never forgets (face eighty-one percent).
(2) My husband took all the money we were saving to buy a new car and blew it all at the (casino: eighteen percent).

To control for the fact that the joke endings are (by definition) unexpected, the straight controls were chosen so that they matched the joke endings for close probability, but were consistent with the frame evoked by context. For example, the straight ending for (1) was name (the joke ending was dress).
while the straight ending for (2) was tables (the joke ending was movies). The close probability of all four ending types (high and low constraint joke and straight endings) was equal, and ranged from zero to five percent. Coulson and Kutas (2001) found that ERPs to joke endings differed in several respects from those to the straight endings, depending on contextual constraint as well as participants' ability to get the joke. In good joke comprehenders, high but not low constraint joke endings elicited a larger N400 than straight endings. This effect may result because the activation of the relevant frame facilitated lexical integration of the high constraint straight endings relative to the jokes. Similar effects may have been absent from the low constraint stimuli, because those sentences led to the activation of a diverse set of frames less likely to be consistent with the straight ending. However, both sorts of jokes (high and low constraint) elicited a late positivity in the ERP (300–900 ms post onset), as well as a slow sustained negativity (200–500 ms post onset), evident over left frontal sites. The effect at left frontal sites has been suggested to reflect the manipulation of information in working memory (Coulson and Kutas, 2001; Coulson and Lovett, 2004). The late positivity is an ERP effect often associated with the activation of information in memory (i.e., retrieval), consistent with the suggestion that joke comprehension requires the activation of a novel frame.

In poor joke comprehenders, jokes elicited a negativity between 300 and 700 ms after the onset of the sentence final word. The absence of the late positivity and the left frontal negativity in the poor comprehenders' ERPs suggests that these effects index cognitive operations important for actually getting the joke. The poor joke comprehenders apparently searched for a coherent interpretation of the joke endings, but because they were unable to retrieve the frame necessary to get the joke, neither the late positivity nor the left frontal effect was evident in their ERPs.

These demonstrations of the brain's relatively early sensitivity to discourse-level manipulations are consistent with the dynamic inferencing mechanisms assumed in many frame-based models of comprehension. Based on computational considerations, Shastri proposed that frame-based inferencing necessary for language comprehension occur in a time frame on the order of hundreds of milliseconds (Shastri, 1999), consistent with our observation that high-level manipulations begin to affect the ERP 200 ms after the onset of a critical word (Coulson and Kutas, 2001; Coulson and Lovett, 2004). In such models, comprehension is achieved by binding elements of the discourse representation to frames in long-term memory (Coulson, 2001; Lange, 1989). Such models help explain how speakers can rapidly and routinely compute predictions, explanations, and speaker intentions (DeLong, Urbach, and Kutas, 2005; Shastri and Ajamianagade, 1993).

2.2 RH and joke comprehension

Researchers in neuropsychology have long noted that joke comprehension is compromised in patients with RH lesions, especially when there is damage to the anterior portion of the frontal lobe (Brownell et al., 1985; Shammi and Stuss, 1999). In one classic study, eight hemisphere-damaged (RHD) patients were given a variety of jokes and asked to pick the punch line from an array of three choices: straightforward endings, non sequitur endings, and the correct punch line. While all matched controls had no trouble choosing the punch lines, RHD patients tended to choose the non sequitur endings, suggesting that the patients understood that jokes involve a surprise ending, but were impaired on the frame-shifting process required to reestablish coherence (Brownell et al., 1985).

The pattern of deficits in RHD patients differs dramatically from those evidenced by LHD patients whose comprehension difficulties are seemingly more severe. To compare the performance of LHD and RHD patients on joke comprehension, Bihlre and colleagues used both verbal (jokes) and nonverbal (cartoons) materials with the same narrative structure (Bihlre et al., 1986). Whether patients received verbal or nonverbal materials, they were asked to pick the punch line (or punch frame) from an array of four choices: a straightforward ending, a neutral non sequitur, a humorous non sequitur, or the correct punch line. Though both patient groups were impaired on this task, their errors were qualitatively different. In both verbal and nonverbal materials, RHD patients showed a consistent preference for non sequitur endings over straightforward endings and correct punch lines (Bihlre et al., 1986). In contrast, LHD patients (who participated only in the nonverbal task) more often chose the straightforward endings than either of the non sequitur endings (Bihlre et al., 1986). These data suggest the deficits RHD patients experience in the comprehension and production of humor is not attributable to the emotional problems associated with some kinds of RHD, as the RHD patients displayed preserved appreciation of the slapstick depicted in the humorous non sequitur endings.

One attempt to link the deficits observed in RHD patients to hemispheric asymmetries evident in healthy adults is Beeman's coarse coding hypothesis (Beeman and Ciarella, 1993). According to this hypothesis, words in the RH are represented by means of wide semantic fields, while words in the LH are represented via a narrow range of features relevant to the immediate discourse context. Although coarse RH semantic activations would predictably include contextually irrelevant information, they might nonetheless be important for the comprehension of figurative language such as that needed to understand jokes. Because jokes frequently require the integration of novel information, the reinterpretation of a word or phrase, and the reinterpretation of the scenario depicted by the preceding context, diffuse RH activation might provide additional information that makes joke processing easier. Similarly, reduced access to these diffuse semantic activations in RH damaged patients could result in joke comprehension deficits. Several studies in our laboratory have addressed whether hemispheric differences in semantic activation are relevant for joke comprehension. In one study, we recorded ERPs as healthy adults read laterally presented "punch words" to one-line jokes (Coulson and Williams, 2005). Parovolos presentation of critical words was intended to affect which cerebral hemisphere received the initial information from the stimulus, and to increase the participation of that hemisphere in the processing of the stimulus. The N400 component was of particular interest, as its amplitude can be interpreted as an index of how hard it is to integrate the meaning of a given word into one's model of the discourse context (Kutas and Hillyard, 1980; Kutas and Van Petten, 1994). As noted above, the critical word in a joke often elicits a larger N400 than a similarly unexpected "straight" ending for the same sentence: the N400 joke effect (Coulson and Kutas, 2001).

We reasoned that if hemispheric differences in semantic activation are relevant for joke comprehension, lateral presentation of joke (GRL) versus straight (BALL) endings for sentences such as "A replacement player hit a home run with this line in different N400 joke effects as a function of visual field of presentation. In this sentence comprehension paradigm, the difficulty of joke comprehension is indexed by the size of the N400 joke effect with larger effects pointing to relatively more processing difficulty. In fact, N400 joke effects were smaller when the critical words were presented to the LVF/RH than the RVF/LH, suggesting joke comprehension was easier with LVF presentation and consistent with the claim that coarse coding in the RH facilitates joke comprehension (Coulson and Williams, 2005).

In a similar motivated study, we measured ERPs elicited by laterally presented probe words preceded either by a joke or by a non-funny control (Coulson and Wu, 2005). Since all jokes turned on the last word...
The activation of pun-related information was assessed by the presence of relatedness effects on the N400 component of the ERP and on one-electrode waveforms that frequently follow the N400 such as the late positive complex (LPC). With an ISIt of zero ms, we observed similarly sized priming effects for both the highly and moderately related probes with RFV (LH) presentation; with LVF (RH) presentation, we observed priming for the highly but not the moderately related probes. With an ISIt of 200 ms, we observed similarly sized N400 relatedness effects for highly and moderately related probes with presentation to the RFV (LH) as well as the LVF (RH). In addition, RFV (LH), but not LVF (RH) presentation, resulted in a larger centro-parietal distributed LPC for related probes. In summary, these results suggest that initially both meanings of a pun were equally active in the LH while only the highly related probes were active in the RH. By 200 ms after the offset of the pun, both meanings were available in both hemispheres.

The LH advantage observed (Coulson and Severens, 2007) may reflect the importance of this hemisphere (especially the left frontal lobe) in coding the association between a word’s form and its meaning. In fact, a neuroimaging study that compared semantic word activations with non-funny controls revealed bilateral activation in the anterior superior frontal cortex, whereas an analogous comparison using puns revealed left frontal activations (Goel and Dolan, 2001). Whereas the temporal lobe activation is primarily a reflection of memory processes necessary for the inferential demands of jokes, the frontal activations to puns were consistent with the need to retrieve word meanings.

Metaphor

A speaker uses a metaphor whenever he or she refers to one domain with vocabulary more generally associated with another. For example, in “I made some good arguments, but he crushed me with statistics,” the speaker uses a term of physical combat, (fired), to discuss the outcome of a verbal argument. Linguistic accounts of metaphor propose that metaphors reflect the output of a cognitive process by which we understand one domain in terms of another (Lakoff and Johnson, 1980). Because classical accounts of metaphor comprehension (Greene, 1975; Searle, 1979) depict a two-stage model in which literal processing is followed by metaphorical processing, many empirical studies have addressed the time course of metaphor processing. Because ERPs provide a real-time index of brain activity related to language comprehension, they have been used to test various models of metaphor comprehension.

3.4 Electrophysiological studies of metaphor comprehension

Pynte and colleagues (1996), for example, used ERPs to address the validity of three hypotheses about metaphor comprehension: the standard model, the parallel hypothesis, and the context-dependent hypothesis. First, the standard pragmatic model posits two discrete stages of metaphor processing, as metaphorical meanings are accessed only after the literal meaning has been rejected. This model predicts an initial effect of metaphors on the N400, reflecting the literal incongruity, followed by a later ERP effect, reflecting the access of the metaphorical meaning. However, although metaphors (Those fighters are lions) elicited slightly larger N400s than literal controls (Those animals are lions) there were no reliable ERP effects after the N400, viz. between 600 and 1200 ms after the onset of the sentence final word. Pynte and colleagues thus suggested that the enhanced N400 to the metaphors reflected participants’ apprehension of the literal incongruity of these sentences, as predicted by the model. However, the absence of late ERP effects is consistent with the predictions of the standard model.

In contrast to the standard model, the parallel hypothesis is that literal and metaphorical meanings are processed in parallel. According to the parallel model, if N400 amplitude reflects the difficulty of comprehending literal meanings, it should also reflect the difficulty of comprehending metaphorical meanings. The parallel model thus entails that differences in the comprehensibility of familiar versus unfamiliar metaphors should be reflected in N400 amplitude. However, when presented out of context, Pynte et al. found no differences in ERPs elicited by familiar metaphors such as “Those fighters are lions,” and unfamiliar metaphors such as “Those apprentices are lions.”

The context-dependent hypothesis is the idea that the metaphorical meaning is directly accessed when it is relevant to the preceding context. To test this hypothesis, Pynte and colleagues recorded ERPs as participants read sentences with familiar and unfamiliar metaphors placed in either relevant (e.g., for the lion example, “They are not cowardly,”) or irrelevant (e.g., “They are not idiomatic”) contexts. The context-dependent hypothesis predicts that regardless of the familiarity of the metaphor, the relevance of the context should modulate N400 amplitude. Accordingly, Pynte et al. found that while metaphor familiarity did not affect the ERPs, the relevance of the context did. Compared to the relevant contexts, metaphors in irrelevant contexts elicited more negative ERPs in both the N400 and the subsequent 600-1200 ms interval, suggesting irrelevant metaphors were more difficult to process.

Further evidence that metaphorical meanings are activated very early in the processing stream comes from an ERP study of the metaphor interference effect (MIE). The MIE is elicited in a sentence verification paradigm in which the subject is given literally true, literally false, and metaphorically true (but literally false) sentences. The MIE refers to the increased response times to reject metaphorically true sentences such as “The dive is a nightmare,” compared to literally false sentences such as “The dive is a table” (Glucksberg, Gideen, and Bookin, 1985). Because the task demands that the participant attend only to the literal meaning of these sentences, the MIE is interpreted as reflecting the automatic activation of metaphorical meanings.
Kazmerski and colleagues recorded ERPs as healthy participants judged the literal truth of metaphorical sentences like "The ravens are a lark's nest."
and "The rumor is a lark's nest." They observed an MIE in participants' reaction times, as it took participants longer to respond "no" to the metaphorical sentences than their literal counterparts (Kazmerski, Blasco, and Deszpeny, 2003). Interestingly, the MIE was only eleven ms in participants with low IQ (≤100), but was thirty-five ms in participants with high IQ (>115). The ERP correlates of the MIE included a smaller N400 for the metaphorically true sentences than the literally false sentences, suggesting participants found metaphorical sentences easier to process than the anomalous endings, as well as a larger late positivity for the metaphors, perhaps reflecting the greater difficulty in responding "no" to these items. Moreover, these ERP effects were marked and robust in the high IQ group, but largely absent in the low IQ group, whose behavioral MIE was also negligible.

Research to date suggests that, contrary to the standard model of metaphor comprehension, metaphoric meanings are available quite early in processing, affecting the ERPs beginning 250–500 ms after the onset of a metaphorical word (Kazmerski et al., 2003; Pynte, 1996). Decontextualized metaphors elicit slightly larger N400 than plausible literal controls such as "Those animals are lions," (Pynte, 1996), suggesting they place more demands on semantic integration processes. However, metaphors elicit smaller N400 than implausible literal controls such as "The ravens are a lark's nest." (Kazmerski et al., 2003), suggesting they are easier to process than incongruous sentence completions. This latter finding casts doubt on the suggestion that the enhanced N400 (relative to plausible literal endings) elicited by metaphors indexes their literal incongruity.

In our model, metaphor comprehension involves coordinating various conceptual domains in the mind. A metaphor is a blend of a verb with a noun, e.g., "He plays doctor," which consists of structure from multiple conceptual domains, and that often develops emergent structure of its own. Metaphor comprehension involves the temporary construction of simple cognitive models along with the establishment of mappings, or systematic correspondences among objects and relationships represented in various models. Mappings are based on relationships such as identity, similarity, or analogy. Consequently, metaphorical meanings—e.g., analogies to link objects in different spaces—do not fundamentally differ from meanings that employ other sorts of mappings.

For instance, understanding the metaphor "All the nurses at the hospital say that surgeon is a butcher," requires coordinating conceptual structures associated with surgery, butchery, and a blend of the two. To understand this metaphor it is necessary to approximate how the nurse and butcher, patient and dead animal (e.g., cow), as well as scalpel and cleaver. However, it also involves construction of a blended model that integrates some information from each of the two domains. In this example, the blend inherits the goals of the surgeon, and the manner of the butcher. The inference that the surgeon is incompetent arises when these structures are integrated to create a hypothetical agent with both characteristics. Similar conceptual operations are involved in understanding literal language. For example, understanding butcher in "During the war, that surgeon had to work as a butcher," also requires the comprehender to establish mappings and integrate information about a surgeon’s training and skill with general information about butchers, and other aspects of the context (Coulson and Matlock, 2001). One might for instance infer that the surgeon was overqualified for his job, or that he was forced to work as a butcher in a labor camp. Differences in the comprehensibility of these metaphor sentences, then, might be less a matter of their figurativity than the extent to which they require the comprehender to activate additional information to establish mappings and integrate it into the blend.

To test these ideas, Coulson and Van Petten (2002) compared ERPs elicited by words in three different contexts on a continuum from literal to figurative, as suggested by conceptual integration theory (Fauconner and Turner, 1989). For the literal end of the continuum, they used sentences that prompted a literal reading of the last term, as in "He knows that whiskey is a strong intoxicant." At the metaphoric end of the continuum, they used sentences such as "He knows that power is a strong intoxicant." The literal mapping condition, hypothesized to fall somewhere between the literal and the metaphorical, is in contexts such as "He has used cough syrup as an intoxicant." Literally mapping stimuli employed fully literal uses of words in ways hypothesized to include some of the same conceptual operations as in metaphor comprehension. These sentences distinguished contexts in which one object was substituted for another, one event was mistaken for another, or one event was used to represent another—all contexts that require the comprehender to set up a mapping, that is, understand a correspondence, between the two objects in question and the domains in which they typically operate.

In the time window in which the N400 is observed (500–500 ms post onset), ERPs in all three conditions were qualitatively similar, displaying similar waveforms and scalp topography, suggesting that processing was similar for all three sorts of contexts. Moreover, as predicted, N400 amplitude differed as a function of the metaphor’s difficulty, with literals eliciting the least N400, literal mappings the next most, and metaphors the most N400, suggesting a concomitant gradient of processing difficulty. The graded N400 difference argues against the literal/figurative dichotomy inherent in the standard model, and the processing difficulty associated with figurative language is related to the complexity of mapping and conceptual integration.

Although the comprehension of metaphoric meanings poses a challenge that is greater than that associated with literal language of comparable syntactic complexity, there may be some support for a view of metaphor comprehension as involving a qualitatively distinct processing mode. ERPs studies of metaphor comprehension suggest metaphorical meanings are active during the same temporal interval as literal meanings (Kazmerski et al., 2002). As in the case of literal language, semantic integration difficulty of metaphoric language is largely a function of contextual support (Pynte, 1996), and may also be attributable to demands of conceptual mapping and blending operations (Coulson and Van Petten, 2002).

3.2 RH in metaphor comprehension

The early theory that the comprehension abilities of the right hemisphere were especially suited for metaphor was based on sparse data, and may have also suffered from the misconception that all forms of both standard and non-standard" language use—metaphor, humor, sarcasm, and so forth—had the same neural bases. Although there is some evidence from the patient literature for greater right (than left hemisphere) involvement in metaphor processing, use of the hemifield priming paradigm has yielded mixed findings on hemispheric asymmetries in metaphor comprehension (see Kacinik and Chiarello, 2007 for review).

In the first such study, Anaki and colleagues had healthy adult participants read centrally presented words with literal and metaphorical meanings, and then make lexical decisions to target words presented, peripherally (Anaki, Faust, and Kravets, 1998). If the prime was stinging, for example, the target might be a word (such as bee) related to the literal meaning of the prime, or a word (such as wasp) related to the prime’s metaphorical meaning. When the stimulus onset asynchrony (SOA) was short (0 ms), both these meanings were primed with RVF presentation, but only the metaphoric meaning was primed with LVF presentation. When the SOA was long enough to index controlled processes (500 ms), only the literal meaning

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was primed with RVF presentation, and only the metaphorical meaning was primed with LVF presentation. Anaki and colleagues argue that these results suggest that metaphorical meanings are initially activated in both cerebral hemispheres, but decay rapidly in the LH while being maintained in the RH. Unfortunately, subsequent attempts to replicate results reported by Anaki and colleagues have failed. Using English materials, Kacinik found that lateral (starring INSULT) priming with RVF/LH presentation at short SOAs, but only lateral priming with an 800 ms SOA. With LVF/RH presentation, lateral priming was observed at SOAs of 100, 200, and 500 ms, while metaphor priming was evident only in accuracy scores, suggesting the activation of the metaphorical meaning in the RH was weak at best (Kacinik, 2003). Further, hemifield priming studies using sentential stimuli have revealed priming for both lateral and metaphorical meanings with presentation to both hemifields (Kacinik and Chiarello, 2007), and that such priming is pronounced metaphor priming with presentation to the RVF (Faust and Wexner, 2006).

In Coulson and Van Petten (2007), participants read centrally presented sentence contexts that promoted either a literal or a metaphorical meaning of the sentence-final word (either the left or the right visual field). Despite other indications that hemifield presentation shifted the balance of activity between the two hemispheres during both early (Ni) and later (post-N400 positivity) stages of processing, the ERP differences between metaphor and matched literal sentence completions were essentially identical after RVF and LVF presentation. In a PET study of neurologically intact adults, Bottini and colleagues observed greater blood flow increase in the right hemisphere when participants read blocks of sentences containing metaphors than when they read literal control sentences (Bottini et al., 2004). However, a more recent functional magnetic resonance imaging (fMRI) study in which task difficulty was well-matched for literal and metaphorical sentences revealed additional LH activation for metaphors (Rapp et al., 2004). Other studies in which investigators have made significant efforts to control for task difficulty have revealed LH activation in comparisons of literal versus metaphorical meanings (Li and Dapretto, 2006; Rapp et al., 2005, submitted). Right hemisphere recruitment may depend on overall task difficulty rather than the figurative nature of the meanings (Coulson and Van Petten, 2003).

A systematic review of a frontal hemodynamic activity reveals that, as a wide variety of tasks becomes more difficult, bilateral increases in restricted areas of frontal cortex are observed, as well as additional RH activation in mid-ventrolateral areas (Duncan and Owen, 2000). Other fMRI studies in healthy adults indicate that when literal sentence comprehension places increased demands upon lexical and syntactic processes, increased activation in both classic LH language areas and in their RH homologues are observed (Keller, Carpenter, and Just, 2003). In general, RH activation is associated with concrete content and disordered course-level processing (Bookheimer, 2001; Kircher et al., 2001; St. George et al., 1996), suggesting that semantic content triggers the recruitment of RH areas. The hemifield presentation paradigm employed in Coulson and Van Petten (2007) had meaning that occurred either the left or the right visual field. However, hemifield presentation did not modulate the size of the N400 metaphor effect, suggesting that both hemispheres are sensitive to the processing difficulty engendered by metaphorically used nouns in sentence contexts. These data are consistent with other recent studies that argue against a privileged role for the RH in metaphor comprehension, and are in keeping with the claim that the brain does not treat literal and metaphorical language as qualitatively distinct categories.

Interestingly, Coulson and Van Petten's results contrast with those discussed earlier that indicate the RH does play an important role in joke comprehension (Coulson and Lovett, 2004; Coulson and Williams, 2005; Coulson and Wu, 2005). This may reflect the fact that appreciation of a joke requires listeners to suppress previously computed inferences and to reweight salient aspects of conceptual knowledge that may be more prominent in the right hemisphere. Because there are many different ways that linguistic utterances can diverge from literality, we should expect to observe a similar diversity in networks of brain areas recruited to comprehend them. We suggest that just as the brain areas activated in the comprehension of literal language differ as a function of the degree to which visual imagery or emotions are evoked (Rizzolatti, Crum, and Crum, 2003; Just et al., 2007), the comprehension of nonliteral language is likely to recruit different brain areas depending on the cognitive processes it engages. Neural resources recruited for metaphor comprehension have been found to vary as a function of factors such as the novelty and complexity of the mapping that also impact the comprehension of literal language (Coulson and Van Petten, 2007; Moshal et al., 2007). Given that metaphor production involves the basic mechanism of meaning extension, perhaps it is not surprising that both hemispheres are similarly sensitive to metaphorical meaning.

4.1 Sensorimotor grounding of concepts

An exciting development in neuroimaging research is the finding that the neural substrate of action and perception is often exploited in higher cognitive activities, including conceptualization that may be important for language comprehension. Sensory regions, for example, are active during sensory processing as well as during sensory imagery (Price et al., 1995). Motor regions are active during the execution of action, but also during motor imagery, as well as during the perception of the motor actions of others (Decety et al., 1997; Deiber et al., 1998; Jeannerod and Decety, 1995; Jeannerod and Prak, 1999).

A series of studies suggests further that modality-specific areas become active in conceptual tasks; for example, color processing regions (i.e., V4) are active for color concepts, motion processing areas (MT/ MST) are active for conceptualizing movement and shape, and visual space (ventral versus dorsal) versus motor (premotor cortex) processing regions for animals versus tools, respectively (Martin, 2001; Martin and Chao, 2001). One issue for future research is whether modality-specific activation occurs in the comprehension of metaphors, idioms, or other sorts of figurative language.

Reasoning on the basis of neural learning mechanisms, Pulvermuller and colleagues have long argued that the neural representation of word meaning must differ as a function of our experience with what those words represent (Braitenberg and Pulvermuller, 1993; Pulvermuller, 1997, 1999). Hebbian learning, for example, is a mechanism by which connection strength between two neurons increases as a function of correlated firing. Because we might expect that words for objects would tend to co-occur with the visual experience of those objects, correlated firing patterns between the neural representations of the word forms and the associated visual experiences would result in the establishment of permanent connections between their neural substrates. Similarly, because words for actions would tend to co-occur with motor activity,
simple Hebbian learning would result in connections between activity in motor cortex and the neural representation of action words (Pulvermüller, 2003).

Similarly, the theory of language (NTT), it has been proposed that language comprehension involves simulating the situation being described (Feldman and Narayanan, 2004). For example, the simulation semantics of NTT suggests that cortical networks that subserve the action of grasping also serve as the neural substrates of the meaning of press. Because metaphor involves exploiting concepts from a concrete domain to understand a more abstract one, this framework suggests that networks that subserve the action of grasping are also activated to understand the metaphorical meaning of grasp. Conceptual blending theory, which suggests that “grasping an idea” involves the parallel activation of an abstract and a concrete meaning of grasp, also makes this prediction (Coulson and Matlock, 2001).

Recent findings suggest the representation of word meaning extends beyond the classic areas determined by the neural psychologists (Damasio et al., 1996; Tranel et al., 1997), and raise the possibility that the neural substrate of metaphor comprehension depends on the particular source (vehicle) and target (topic) domains of the metaphor. In this framework, one would not necessarily expect actions to be processed in a single brain area, or even a particular network of brain areas. Rather, action metaphors would be expected to recruit brain areas underlying the comprehension of action, while spatial metaphors would be expected to recruit brain areas that subserve spatial cognition.

The idea that conceptual knowledge is grounded in sensorimotor experience is closely related to the claim in cognitive linguistics that metaphorical understandings of abstract domains recruit concepts from more experientially basic ones (Lakoff and Johnson, 1999). One example for which there is some empirical support is that the abstract concept of numbers is understood by recruiting spatial concepts in the metaphor of numbers as points on a spatially extended line. Inherent in the concept of a number line, this metaphor posits a mapping or correspondence between particular numbers and particular regions in space such that quantity goes from left to right, with the largest numbers mapping onto the right-most regions of the line.

This predicts that neural structures that support spatial reasoning will be systematically recruited in numerical operations, and that damage to brain structures involved in spatial reasoning will also have a detrimental effect on numerical calculations that recruit the mental number line. In fact, neuroimaging studies show that right intraparietal areas important for visuospatial processing are consistently activated by number comparison tasks (Chochon et al., 1999; Pined et al., 2000). Further, the prediction of damage to the underlying substrate of visuospatial processing is borne out by the fact that hemineglect impacts various arithmetic tasks.

Hemineglect is a neurological condition resulting from lesions to the RH parietal lobe in which the patient has difficulty attending to or responding to stimuli on one side of space. Consistent with a mapping between numbers and regions of space, hemineglect patients have been shown to be impaired when making judgments about numbers to the left of a reference number on a linear number line. For example, when asked to judge whether a target number was to be processed in a single brain area, or even a particular network of brain areas. Rather, action metaphors would be expected to recruit brain areas underlying the comprehension of action, while spatial metaphors would be expected to recruit brain areas that subserve spatial cognition.

5 Conclusion

Cognitive neuroscience data argue for a dynamic, context-sensitive language processor capable of handling a diverse array of figurative language phenomena. Indeed, this context sensitivity may arise naturally out of the way in which information is stored in the brain. Modern neuroscientists understand memory as experience-driven changes in the brain that affect subsequent behavior (e.g., Fuster, 1997). The fundamental mechanism for memory formation is Hebbian learning, in which synaptic connections between neurons are strengthened as a result of temporally coincident firing (‘cells that fire together wire together’). Associations result in the formation of cell assemblies that serve as the functional units of memory, and “retrieval” is the transient activation of a cell assembly.

As memory is stored in overlapping and distributed networks of neurons, spatial metaphors for memory are not particularly apt. Information in memory does not exist in a particular place, but rather is inherent in the connections between the neurons in a cell assembly that facilitates their synchronous activity. The same neurons that mediate experience—perception and action in the world—also mediate information for that experience. Further, because of the transient nature of cell assemblies, semantic memory representations are not constant, but change as a function of experience and context. The idea of language comprehension as a process of activating and linking information in memory follows from neural processing mechanisms that are fundamentally constructive. Indeed, the commonplace nature of figurative language may reflect the fact that meaning construction processes are fundamentally imaginative.

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